

## **HELP – A Program for Medical Decision-Making\***

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### **Introduction**

The rapid growth in useful medical knowledge has made it increasingly difficult for a physician to stay abreast of improvements in diagnosis and management of patients with a wide variety of diseases and disease combinations. For example, a general practitioner may admit a patient to a coronary care unit only infrequently and yet be faced with the problem of making decisions regarding this patient during his stay in such a unit. Care of this patient requires him to be aware of many developments perhaps only published in certain specialty journals. The program described in this paper was designed not only to make available to such a physician, through the help of a time-shared computer system, the current data on his patient, but also by storing the logical basis for making decisions from this data, suggest to him decisions when the data from his patient satisfies this logic. This system can only be effective when coupled to a patient-oriented computer-based medical record (*I*), but on the other hand, by explicitly stating the data requirements for making these decisions, the important contents of the medical record are directly specified.

### **Program Objectives**

The program (HELP) is designed to help the physician or nurse with the intellectual task of recognizing the occurrence of preset conditions which indicate nodes of decision points in a patient's illness. Such a node may arise from one or more new entries into the patient's record. Each of these decisions must represent the best in current medical knowledge and be easily modified without alteration of the program itself new information becomes available. The form in which these decisions are specified must be understandable to the physician. The data base upon which decisions are made may originate from manual entries, automated reading of

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physiological transducers or laboratory devices (autoanalysers, etc.) or as the result of prior decisions made by HELP itself, thus establishing a hierarchical data structure and information system. The system also provides ready access, not only to raw data and trends in any variable (2), but to all currently relevant decisions previously made on a patient in a manner not unlike the problem-oriented medical record (POR) of Weed (3). The basis for each decision is displayed to the physician on request so that he may review the pertinent data himself. This not only provides a potent teaching mechanism but may also permit the detection of errors in decision logic which can then be corrected. Only through such a mechanism can HELP really reflect the best thinking on a particular subject. Finally, the program is usable on simulated data and thus provides a basis for teaching and testing of a physician's decision making capabilities in any particular specialty area.

## Environment

HELP operates under the MEDLAB time-sharing monitor (4, 5) on a Control Data 3300 Computer. This is a multiprogramming system that allows each user 2000 words of memory and provides him with resident utility subroutines which are reentrant for such tasks as disc access, graphic and alpha-numeric display on scope terminals, and overlaying one program with another to any depth. Also, the monitor provides access to a patient record system on magnetic disc which is open-ended both in terms of record length and content (1). Each field has a unique identifier which also contains the number of words of data in the field and the time and date of the entry (or of the occurrence of the phenomena which the data represents). All data is stored chronologically within a given patient record.

A patient's record is initiated on disc either at the time of his admission to the hospital or at the time he goes through the automated preadmission screening procedure several days prior to his admission. All scheduled admissions (non-emergency) pass through the screening procedure where they receive the following tests and the data is logged into their computer record: (1) Self-administered history (one bit is used to represent the answer to each of 280 questions), (2) Electrocardiography (--- parameters are stored as well as bits representing the ECG diagnosis for both morphology (6) and rhythm), (3) Spirometry (values are stored for absolute volume and flow as well as percent of expected values based on age, sex, height and weight (7)), (4) Intraocular pressure, (5) Blood chemistry, (12-channel autoanalyser on-line from the clinical laboratory), and (6) Certain manually entered data which includes age, sex, height, weight, blood pressure and the results of hematological analysis and urinalysis. Any subsequent tests for the above variables are also entered, and in the case of the ECG, a separate analysis for change since the last ECG is included (8). Although all patients admitted to the hospital have a computer-based record, some will have much more information in this record than others. Records on those patients who undergo heart catheterization will include all measurements of pressure, oxygen saturation, and parameters measured from indicator dilution curves, as well as any comments or observations made by the physician performing the procedure (9) (entered manually as codes from a terminal in the laboratory). Records from patients monitored in the operating room or intensive care units (ICU) (43 beds in 5 hospitals) will contain not only cardiovascular measurements such as stroke volume, systolic pressure, heart rate, etc., every 2 to 15 min, but also clinical information such as medications, fluid intake and output, and clinical observations such as rales, coma, etc., entered by the personnel in the operating room or ICU (2,10). Special

coding systems have been devised to enter data from X-ray and from the coronary care unit to fit their particular needs.

At the time of discharge from the hospital a variety of additional data is entered from a terminal in the medical record department in order to complete the file prior to transferring it from disc to tape where it is stored for later use in research and medical audit. This includes the discharge diagnosis coded in SNOP as modified in this department by J. Morgan (11) using a program which codes automatically, starting from the first few letters of the key words in each category (topology, morphology, etiology and function). The surgical codes and pathologists diagnoses are entered using the same system.

## Program Design

HELP is designed to permit the definition and storage of decision criteria and the ready analysis of a patient's record using these decision criteria whenever appropriate. HELP itself is simply a program for interpretation of decision criteria stored on disc in light of current data and prior decisions on a patient. Each decision requires one sector (64 words, 24 bits each) of disc space and is represented by four components of 16 words each.

Component 1 is either a message to be written on the user's terminal if the decision is true (Fig. 1), or a list of other decisions (relative sector addresses) to be evaluated if the decision is true (direct reference). The latter type sector provides the mechanism for deciding whether a given set of decisions should even be evaluated. This represents a tree structure to sequence the set of decisions examined directly in a dynamic fashion and makes it possible for the physician to construct his decision list to by-pass decisions for which a "no" (false) answer can already be inferred (i.e., look for other ECG diagnoses only if the ECG data fails to satisfy the criteria for normal).

Component 2 consists of a Boolean statement of up to 64 characters including 0-9, A-F, (,),\*,+, and -, where \* represents a logical "and", + is "or" and - is "not". For example, (0\*1\*(-(2 + A))) is read as "this statement is true if item 0 and item 1 are true and neither item 2 nor item A is true". The presence of an illegal Boolean statement (illogical) is recognized by the program when it is encountered, but, of course, errors in the medical logic must be detected by the user. Use of the nesting feature described below permits this logical string to be as long and complex as needed.

Component 3 of each sector has 16 words, each of which refers to an element in the logical string and identifies the type of data, the explicit field code identifier, and word or bit number within the field where the variable in question is stored. The allowable element types are: (1) COD data which is entered automatically from some device or transducer (i.e., pressure data from patient monitoring or ECG parameters from the ECG program), (2) COM data which is entered manually using a comment library of 4 digit numbers. Each number identifies the type of data (i.e., penicillin) and is followed by other information such as dose and route or the number is the data itself (i.e., rales), (3) BIN data represented in the patient's file by a single bit (i.e., answer to a question on the history questionnaire), (4) ADD-refers to the sector address of another decision which must then be evaluated before this element can be treated as true or false, and (5) OLD-examines bits set by previous decisions made by HELP and stored in a special sector (1536 bits-problem-oriented record, POR) for each patient (i.e., some sectors for interpretation of hemodynamic data during heart catheterization refer to decisions made at the time of the ECG analysis).

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CONTENTS OF SECTOR      1

MESSAGE

**** $SPACE$IMMEDIATELY$$ ****

BOOLEAN STRING

((0+(1*(2+4+((5+6)*(-3))+7+8+9+A+B+C+D+F)))*(-E))

INDEX  TYPE    CODE  WORD  LOGIC  VALUE  VARIABLE
*****
0      COM     3542   1     5 HRS   24     MOBILTZ
1      COM     3541   1     5 HRS   24     COMPLETE A/V BLOCK
2      COD     11020  8     2 LT    50     HEART RATE BY EKG
3      COD     11020  3     0 EQ    0      CARDIAC OUTPUT
4      COM     3434   1     7 ANY   0      ANTERO SEPTAL MYOCARDIAL INFARCT
5      COD     11020  6     2 LT    90     SYSTOLIC PRESSURE
6      COD     11020  3     2 LT    30     CARDIAC OUTPUT
7      COM     6306   1     2 LT    70     MVO2 SATURATION      0 PERCENT
8      COM     3210   1     5 HRS   24     CONFUSED
9      COM     2303   1     1 GE    150    VENOUS PRESSURE      0.0 COM
A      COM     2324   1     1 GE    20     PULMONARY ART, PRESS, 0 MMHG
B      COM     3426   1     5 HRS   24     BILATERAL BASAL RALES
C      COM     3437   1     7 ANY   0      INFERIOR MYOCARDIAL INFARCT
D      COD     23     1     2 LT    90     OXYGEN SATURATION RADIAL ARTERY
E      COM     1104   1     7 ANY   0      INSERT TRANSVENOUS PACER
F      COD     11     1     2 LT    70     OXYGEN SATURATION MAIN PULMONARY ART

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Fig. 1. The decision criteria for the message "Pace Immediately" (\$'s are for scope line control). The Booleans string contains up to 64 characters matching those of the "index" list linked by the logical operators \* "and", + "or" and - "not".

The 4th component contains one word for each of the 16 elements in component 3 and the contents of each word depend on the type of data involved. For COD data, a logical operator such as (0) any value, (1) greater than or equal to X, (2) less than X, (3) arithmetic operator (see below), (4) within last X days, (5) within the last X hours, (6) within the last X minutes, or (7) equal to X, where X is a value also stored in this word. In the case of the arithmetic code, a second code specifying the type of arithmetic operation to perform is packed in place of X. These codes are: (1) to add this variable to the next variable in the list, (2) to subtract it, (3) to multiply it, (4) to divide it into the next item, and (5) to multiply the next variable by 100 before performing the division. An example which illustrates the use of this system is the diagnosis of atrial septal defect shown in Fig. 2. The effective operation performed by items 0-3 is ("2" plus "3") minus ("0" plus "1")  $\geq 12$ , or, in other words, if the difference between the oxygen saturation in the mid-right atrium and the average of superior and inferior venacaval saturation is greater than 6, item 3 is true. Items 0, 1, and 2 will not appear in the Boolean statement since they have no meaning except as modifiers of item 3 (the first nonarithmetic operator following them).

From COM data, the 4th component is the corresponding logical operator and value as with COD data, but most commonly the time operators 4, 5, or 6 are used. For BIN data, this component is the bit location in the field specified and the item is set to 1 (true) if this bit is 1. For an ADD item, this component is not used, but the decision on the sector whose address is referenced by component 3 is evaluated. To accomplish this the current sector (containing the reference) is entered into a push down stack and the new sector is evaluated before returning to complete the present sector. Up to 4 levels of nesting on a first-in, last-out basis are permitted in the present version of HELP and internal checks are provided to prevent infinite loops which could occur if a sector, referenced directly or indirectly from an original sector, referenced in

turn a sector already on the stack. If a sector has already been evaluated as "true" or "false," this information is saved so that any subsequent reference to it directly or indirectly will not cause it

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CONTENTS OF SECTOR          148

MESSAGE

**** $ATRIAL$SEPTAL$DEFECT WITH$LEFT TO RIGHT$SHUNT$$          ****

BOOLEAN STRING

(( (3*9)*(-(4+5)))*(-(A+B)))

*****
INDEX  TYPE    CODE  WORD  LOGIC  VALUE  VARIABLE
*****
0      COD      1     1     3 ADD    1     OXYGEN SATURATION    SUPERIOR VENA CAVA
1      COD      5     1     3 SUBT    2     OXYGEN SATURATION    INFERIOR VENA CAVA
2      COD      3     1     3 ADD    1     OXYGEN SATURATION    MID RIGHT ATRIUM
3      COD      3     1     1 GE     12     OXYGEN SATURATION    MID RIGHT ATRIUM
4      COD     23     1     2 LT     89     OXYGEN SATURATION    RADIAL ARTERY
5      COD     24     1     2 LT     89     OXYGEN SATURATION    FEMORAL ARTERY
6      COD     201     1     3 ADD    1     OXYGEN SATURATION    SUPERIOR VENA CAVA
7      COD     205     1     3 SUBT    2     OXYGEN SATURATION    INFERIOR VENA CAVA
8      COD     203     1     3 ADD    1     OXYGEN SATURATION    MID RIGHT ATRIUM
9      COD     203     1     1 GE     12     OXYGEN SATURATION    MID RIGHT ATRIUM
A      COM     4112    1     7 ANY     0     PULMONARY VEIN VIA R.A.
B      ADD      150                      $ATRIAL$SEPTAL$DEFECT WITH$BIDIRECTIONAL$SHUNT$

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Fig. 2. The decision criteria for "Atrial Septal Defect with Left to Right Shunt". This sector is an example of the use of arithmetic operators identified as logical operator 3 and "value" 1 to add and 2 to subtract. "Codes" 1, 5 and 3 are the oxygen saturations for a patient breathing room air at rest, while "codes" 201, 205, and 203 are the oxygen saturations breathing oxygen at rest.

to be reevaluated. If a sector is referenced indirectly (as an element of another sector) and found to be true, only the corresponding item in the calling sector is set to 1. If a sector is referenced directly, other actions may be initiated such as writing the corresponding message on the terminal, calling a list of other sectors or setting the corresponding bit in the patient's "POR" for reference by some subsequent decision. This is useful in comparing present state with a prior state as in the case of serial interpretation of the electrocardiogram.

The program may be called either directly or indirectly as an overlay to another program. When called directly from a terminal, the user is presented with a list of options from which he must choose the area of interest for a particular decision (Fig. 3). His choice determines the initial sector to be evaluated and this sector then links (calls directly) the other sectors pertinent to the chosen decision set. If HELP is called indirectly (i.e., from the catheterization laboratory control program or from the CCU monitoring program) the options are not displayed since the option is passed from the calling program to HELP. Not only does the decision area determine the set of possible sectors to evaluate directly, but it also provides a complete list of the relevant field codes for this set of decisions. This list is used to allow the program to generate an abstract of the patient's record containing only these codes so that search time can be minimized in the sector evaluation stage. This feature is particularly useful in the case of ICU and CCU patients who may acquire very large data files. This abstracting overlay is only called if the patient has more than one page (512 words) of data. To date no decision set (up to 60 sectors) requires more than 6 secs to complete except when time sharing is particularly heavy.

A directory which references up to 1000 patient's POR sectors is maintained by the program. The position of the patient's sector is located from the location of his hospital number in this

```
ENTER PATIENT
NUMBER      S
1    EKG
2    CCU
3    CATH LAB
4    PULMONARY
5    POSTOP
6    HEART
7    SCREENING
8    RHYTHM
```

Fig. 3. The list of options presented when "HELP" is called directly. The choices are: (1) Interpretation of the patient's electrocardiogram, (2) Decisions to be made in the coronary care unit, (3) Diagnostic decisions based on heart catheterization data, (4) Diagnostic decisions based on pulmonary functions data, (5) Decisions to be made in the postoperative intensive care unit, (6) Diagnostic decisions based on clinical observations prior to heart catheterization, (7) Decisions based on screening laboratory and history data, and (8) Interpretation of cardiac rhythms.

directory. On discharge, his number is replaced by zero making room for a new patient and his POR is transferred to tape along with the rest of his data. On demand, all current decisions on a given patient can be displayed on any terminal by entering his hospital number. Each bit set to 1

```
PACE
IMMEDIATELY

BECAUSE PT. HAD

1 COMPLETE A/V
BLOCK HRS      24

2 SYSTOLIC
PRESSURE LT     90

3 CARDIAC OUTPUT
LT             30
```

Fig. 4. A list of the conditions which developed in a patient and caused the decision to be made to "Pace Immediately". These are: (1) Complete A/V heart block occurring within the past 24hr, (2) Systolic pressure that is now less than 90 mm Hg, and (3) Cardiac output that is less than 3 liters/min (shown in tenths of a liter).

causes the corresponding sector to be read from disc and component I (if a message) to be written out on the terminal display or printer.

Another feature of the program permits the user to ask for the reasons a particular decision or set of decisions was made. This is made possible by HELP maintaining a trace of each decision

which is saved temporarily on disc if the decision is true. Requesting this option following a presentation of a decision statement causes another program (BECAUSE) to be called as an overlay. This recalls the trace data and presents the particular elements of the Boolean statement which caused it to be true (Fig. 4). Not only does this serve as a teaching tool, it also gives the physician or other attendant the facts upon which the logic was performed so that he may indeed assume the responsibility with full knowledge for any action that may follow.

Finally, a program (LINK 2) has been written which generates data to simulate a real patient using a table of probabilities and a random number generator. Tables were developed for clinical observations, X-ray findings, laboratory findings, hemodynamic data, and ECG diagnosis which contain the field codes for each item from one of the above categories which contributes to any decision and a corresponding number representing the probability that any particular measurement (observation) would result in that finding or value. The student chooses a category such as clinical, and the program randomly (according to the clinical table of probabilities) chooses a finding and presents it to the student. At the same time, this choice influences future choices by the program by causing a new table of probabilities to replace the old clinical (or X-ray, etc.) table, thus making it more likely that the subsequent choices will be in line with a decision related to the first choice.

The student has options which allow him to collect more data from any of the above categories, to review data collected already on this "patient", or call HELP which performs the decision logic exactly as it would on a real patient's data. If a decision is made, it is presented on the terminal display. The BECAUSE option is also available to explain each decision. LINK 2 not only serves as a teaching and testing tool, but also, because it uses the same data handling routines as are used on real patients, is valuable to the programmer and medical expert who specified decision logic for HELP as a means for rapidly testing decisions under a wide variety of conditions which might take months or years to encounter in real patients. This program can be called from any terminal by anyone who has the time and the desire to gain experience.

## Discussion

Decision sectors have been generated and are now operational for five areas in the hospital, namely, coronary care unit, electrocardiography, cardiac catheterization laboratory, pulmonary function, and clinical cardiology. Decision sectors for preadmission screening are now being developed. The program serves a somewhat different purpose in each of these areas. For instance, in coronary care unit it serves as an alarm system for those patients being monitored. Each new entry into the patient's file causes HELP to be executed in the light of current data and if a decision is made, a red light is turned on in a panel at the nurse's console corresponding to this bed. The nurse presses this light switch causing the computer to display the decision message. Pressing the send button once more causes the explanation to appear on the terminal.

During a heart catheterization the program serves quite a different function. The physician may at any point in the procedure press a key on his console causing HELP to examine old data collected and display any diagnoses so far established by the logic previously stored in the decision sectors. This permits him to see whether he has stored the essential data needed to establish the diagnosis and in addition may alert him to unexpected decisions implied by his data. If the physician recognizes an error in the diagnosis due to incomplete data or bad data, he may make additional measurements or edit out bad data in order to make the data satisfy the criteria for the correct diagnosis before terminating the procedure and printing the report which includes

the diagnosis made by HELP. In the case of electrocardiography, pulmonary function, and clinical laboratory, the HELP program is called automatically at the end of the data collection and analysis programs and serves to summarize the data and store the decision bits so that they can be accessed as part of other HELP decisions or can be printed out or displayed on request from any terminal.

The cost of operating HELP may be analyzed in terms of storage costs and computer time. One sector on disc is required to store each decision and costs about 10¢ per year. The CPU time required for each HELP run on the CDC 3300 is approximately 5 sec for a typical set of about 50 decisions representing one decision area (i.e., heart catheterization) at a cost of 14¢. In addition, there are the costs of data entry and storage, but these costs may well be justified for other reasons such as intra-hospital communication, generation of serial cumulative reports, trend analysis, medical audit and research. Also, most of the data entry programs provide some on-line analysis and useful output at the site of entry as well as immediate quality control of the input. Although HELP may not be the primary reason for entering and maintaining a computer-based medical record at the present time, it may well provide the most useful output from this system in terms of direct effect on medical care as more decision sets are generated and refined and additional points of access become available within the hospital.

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